A STUDY EXAMINING THE POSSIBILITY OF OBTAINING TRACEABILITY TO UK NATIONAL STANDARDS OF TIME AND FREQUENCY USING GPS-DISCIPLINED OSCILLATORS

J. A. Davis and J. M. Furlong

Centre for Time Metrology,
National Physical Laboratory,
Queens Road, Teddington, Middlesex, TW11 0LW, UK

ABSTRACT

In the UK there is considerable interest in using GPS-Disciplined Oscillators (GPSDOs) as standards traceable to UTC(NPL). However, UK accreditation bodies are somewhat reluctant to accept GPSDOs as traceable standards, without a detailed study of the practical issues involved in establishing traceability. NPL has undertaken an extensive study, examining the performance of 15 GPSDOs loaned by 11 UK suppliers and manufacturers, to address this traceability issue. In this paper a detailed account is presented of the results obtained from the NPL study. A preliminary set of recommendations on the use of GPSDOs as standards traceable to UTC(NPL) have been produced. The progress made on implementing a mechanism enabling GPSDOs to be recognized as standards traceable to UTC(NPL) is outlined.

1) INTRODUCTION

GPS-Disciplined Oscillators (GPSDOs) are widely used in the United Kingdom as standards of time and frequency. GPSDOs combine the long-term stability of the timing signals available from the GPS with the short- and medium-term frequency stability available from quartz or rubidium oscillators. The growth of the use of GPSDOs in calibration laboratories in the UK has been limited because GPSDOs have not been recognized as standards traceable to the UK national time scale UTC(NPL). GPSDOs offer many advantages over other time and frequency standards. The global nature of the GPS enables GPSDOs to be used anywhere in the world. The quality of the timing signals results in an improved accuracy over frequency standards disciplined by terrestrial standard frequency transmissions. GPSDOs do not require periodic re-calibrations, they are not excessively expensive, costing typically between £2,000 and £12,000. GPSDOs have many applications world-wide, in particular within the telecommunications industry.

NPL has responded to the growing interest in using GPSDOs as traceable standards, by

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- Produce a report now forwarded to UKAS [5], describing the findings of the study, which includes a series of recommendations on the operation of GPSDOs when used as traceable standards.

Measurements were performed between January 1997 and April 1997. Eleven organizations provided NPL with 15 GPSDOs. In addition three GPSDOs were monitored at other laboratories within the UK. The participants in the study were: Absolute Time, Datum, Efratom, Hewlett-Packard, Motorola, Navstar, Radiocode Clocks, Rapco Electronics, Quartzlock, Tekelek, Trak, and Truetime.

3) EXPERIMENTAL MEASUREMENTS

A 16-channel phase comparator (TimeTech model PComp 16-001/96) was used to compare the GPSDO's frequency output, against the standard frequency output from NPL's active hydrogen maser (Sigma Tau, model MHM 2010) generating UTC(NPL). The phase differences were recorded every second.

Four 1-nanosecond resolution counter timers (Racal Dana Universal Counter Timers, model 1991) were used to compare the 1PPS signal generated by each GPSDO against a 1PPS signal derived from UTC(NPL). Two double four-way switch boxes (Hewlett-Packard Model 59307A) were used to monitor the output from each GPSDO in turn. This switching arrangement resulted in a duty cycle of one minute on, three minutes off.

Status information on both the performance of each individual GPSDO and on the GPS constellation was obtained from the RS232 serial communications port. All available data sets were recorded once per minute during the duration of the study.

Three eight-channel GPS receivers were used to continuously monitor the GPS signals received at NPL during the study. These included one Allen Osborne Associates TTR-4P receiver and two Motorola VP Oncore receivers (with the Z option). The Motorola Oncore receivers were particularly valuable, being inexpensive C/A code receivers, similar to those used in most GPSDOs.

Both the local temperature and the humidity of the environment were recorded using three Grant Squirrel Logger Model No. 1200. Published information on the status of the GPS and on UTC(USNO) - GPS Time have been obtained from the USNO WWW site. Internal cable delays between UTC(NPL), the 1PPS logging system and each GPSDO 1PPS output were calculated using a portable cesium clock (Hewlett-Packard model 5071A, high performance option).

4) STUDY RESULTS

Examples of plots of the extended measurements of UTC(NPL) - GPSDO(1PPS), calculated

In almost all cases, the disciplining process improves the long-term performance of the GPSDO. However, this is at the cost of degrading the short/medium-term performance. This degradation is clearly observed in the example shown.

The averaging time (τ) at which the degradation of the GPSDO performance is at its worst depends both on the type of local oscillator and on the time constant of the disciplining algorithm. The performance degradation was generally worse with quartz-based GPSDOs and occurred at shorter averaging times.

Around 30% of the GPSDOs under study displayed time and frequency transients of amplitude greater than 100 ns. Examples of a typical transient are shown in Figures 7 and 8 showing both the changes in UTC(NPL) - GPSDO and changes in fractional frequency offsets. When transients occurred, they were observed in both the phase and 1PPS outputs of the GPSDOs. The majority of the transients followed the same pattern. There was a sudden change in the GPSDO frequency, possibly due to a sudden change in the DAC value. The "normal" disciplining process of the GPSDO will then restore the time and frequency outputs of the GPSDO to within their "normal" operating range. These transients may last for several hours and may seriously undermine the use of GPSDOs as traceable standards of time and frequency.

Correlation effects between GPSDO outputs have been investigated. Some strong correlations were observed. An example is shown in Figures 9 and 10; the sum and difference of the two UTC(NPL) - GPSDO outputs are plotted. These results were obtained from two quartz-based GPSDOs. The correlation effects were strongest for quartz-based GPSDOs where the time constants for the two disciplining algorithms were similar. The correlation effects are due to the reception of common GPS signals by the GPSDOs, the performance of both GPSDOs being limited by the presence of the same SA signal degradation.

The GPSDO antenna coordinate determination has been investigated and compared with the coordinates determined from site surveys undertaken at NPL. The GPSDO coordinate errors range from 1.6 m to 51 m, the mean coordinate error being 21 m . Most GPSDOs are operated under a "position hold" mode when the first 24 hours or longer of data collected are used to determine the antenna coordinates. These coordinates are then "fixed" and are used for time and frequency dissemination. A few GPSDOs operate using instantaneously determined positions; however, there was a noticeable increase in the scatter on the resulting time and frequency outputs of these GPSDOs. Some GPSDOs operate from coordinates determined from continuous extended averaging. The performance of these GPSDOs were equivalent to those operating using a position hold mode. Where there was a combination of an extremely stable GPSDO and poor antenna coordinate determination, then the determination of the antenna coordinates may limit the GPSDO performance.

Substantial monitoring took place of the GPS signals received at NPL. Peak-to-peak variations of several 100 ns were observed. This is at the limit of what would be expected from the effects of SA.

with an accuracy of only a few microseconds is required, then all of the GPSDOs under examination would be suitable. The performance of the GPSDOs under non-ideal operating conditions suggests that there is a high degree of integrity in the GPSDOs' performance. However, the behavior of GPSDOs has not been tested in the presence of highly erroneous GPS signals. The above issues have given careful consideration when formulating the recommendations outlined in Section 6.

6) TRACEABILITY RECOMMENDATIONS

NPL has produced a set of provisional recommendations on the use of GPSDOs as standards traceable to UTC(NPL). These recommendations may be revised in the light of future studies or after discussions with other interested parties within the UK. NPL recommends that:

- NPL should monitor the GPSDO constellation from its Teddington site, and publish to the UK time and frequency community information on any GPS system anomalies.
- Values of UTC(NPL) - UTC(USNO) should be regularly published by NPL.
- NPL should produce a sample error budget for a typical GPSDO based on the GPS user range errors and supported by empirical measurements. Error budgets of this type may then be used to set the accuracy levels of the traceability for individual models of GPSDOs.
- Each manufacturer's model of GPSDO should be characterized for both its time dissemination and frequency dissemination properties. The characterization of individual models of GPSDOs is sufficient if conservative error budgets are used in establishing traceability.
- To achieve traceability for the highest accuracy time dissemination, (uncertainties < 1,000 ns) each individual GPSDO should be calibrated against a primary time scale. Two co-located GPSDOs should be operated at each location, so as to check for systematic delay changes. When considering time dissemination traceability, there is a need to calibrate the GPSDO internal delays, as these can dominate the error budget.
- The frequency stability and accuracy of a GPSDO be specified at the averaging times appropriate to the measurement process, and that the specified performance is validated by measurement traceable to a primary time scale.
- Unless a model of GPSDO has been shown not to be vulnerable to transient effects, either two GPSDOs should be operated in parallel, or a single GPSDO should be operated alongside a highly stable local oscillator, so that transients may be identified.
- Sufficient sky should be visible for the GPSDO to continuous observe the number of

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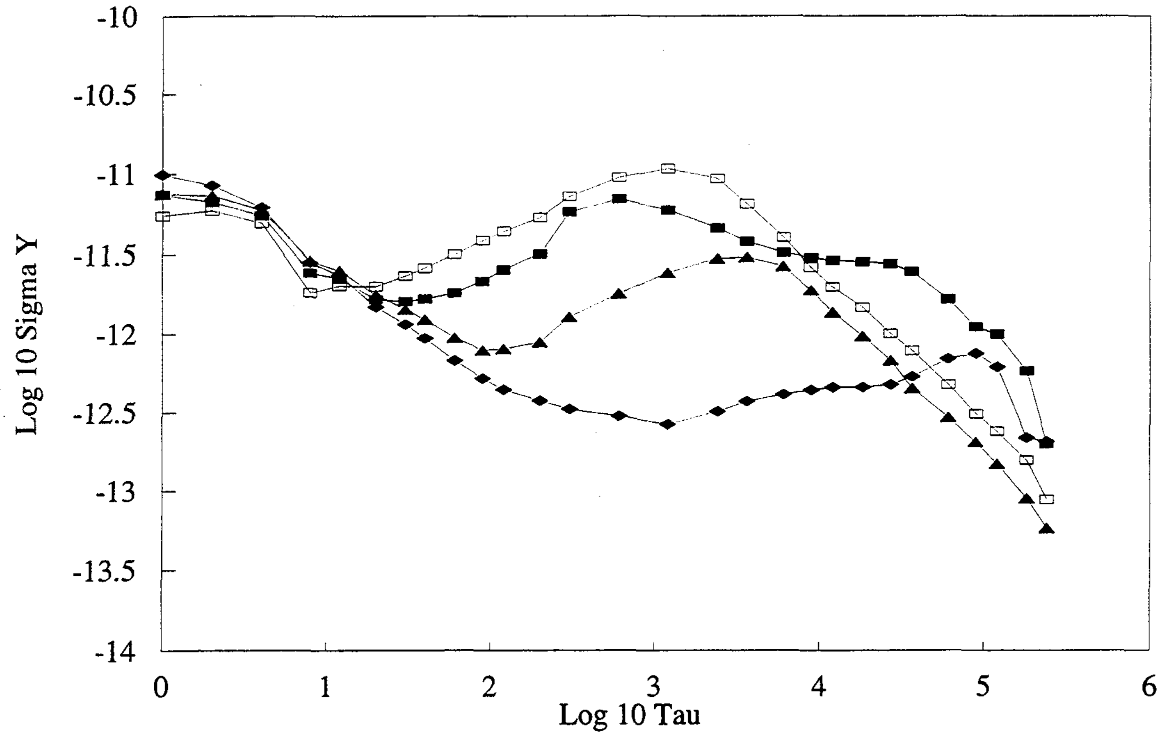

Figure 3: Graph of Log10 Sigma Y against Log 10 Tau - phase of GPSDO reference frequency

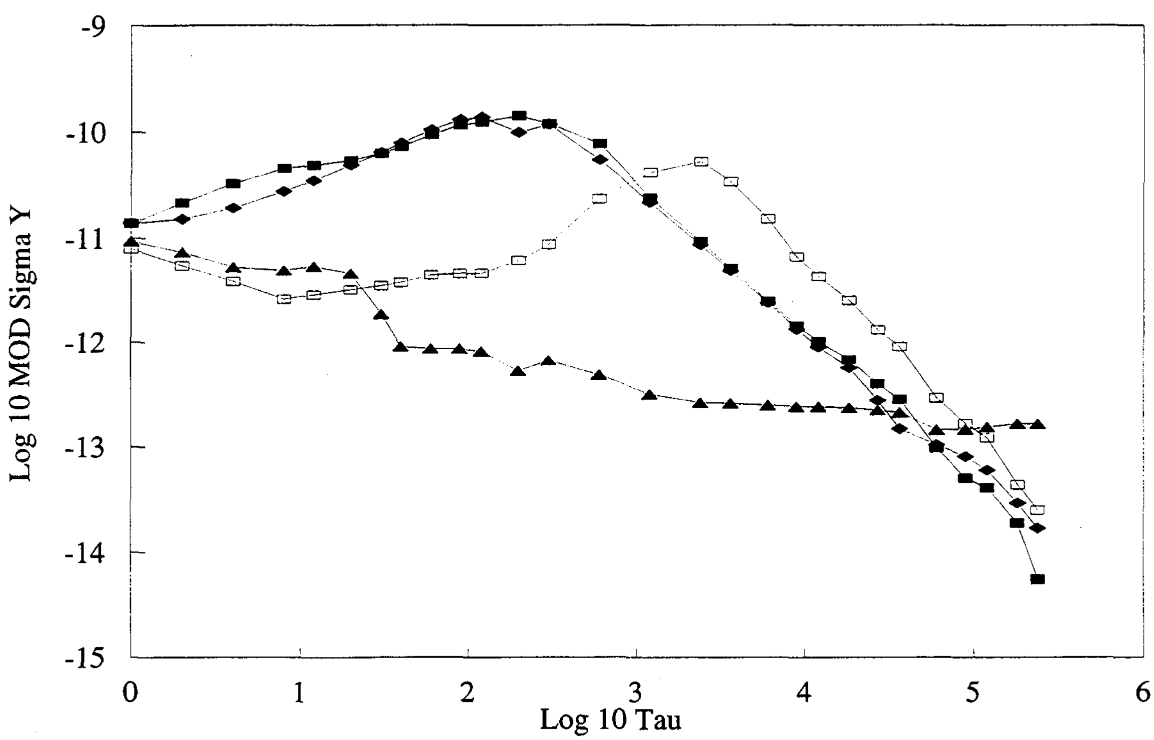

Figure 4: Graph of Log10 MOD Sigma Y against Log 10 Tau - phase of GPSDO reference frequency

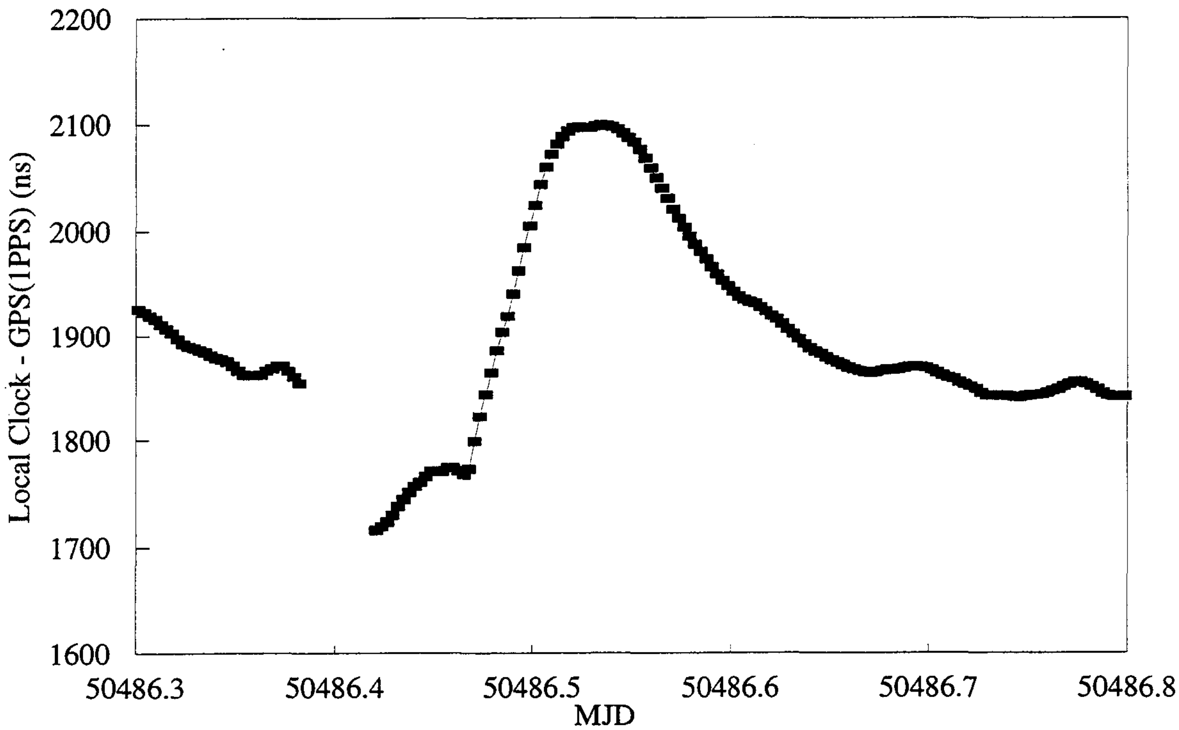

Figure 7: Time and frequency transient

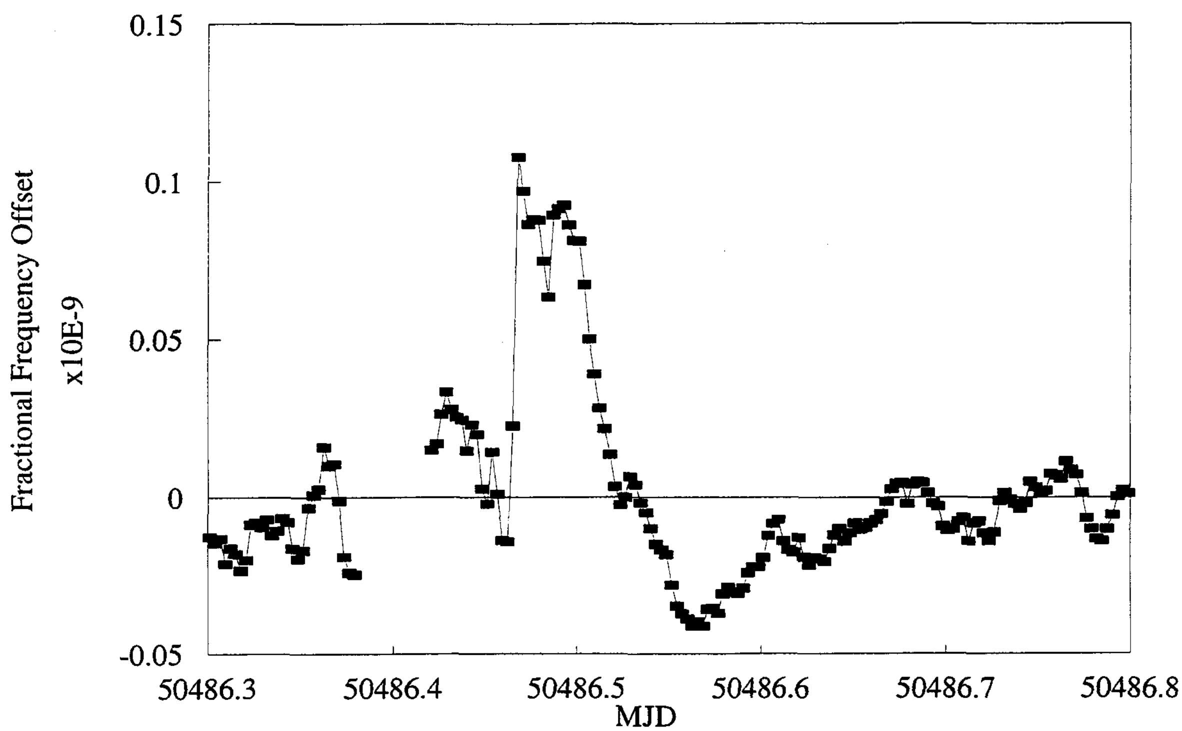

Figure 8: Time and frequency transient - fractional frequency offset

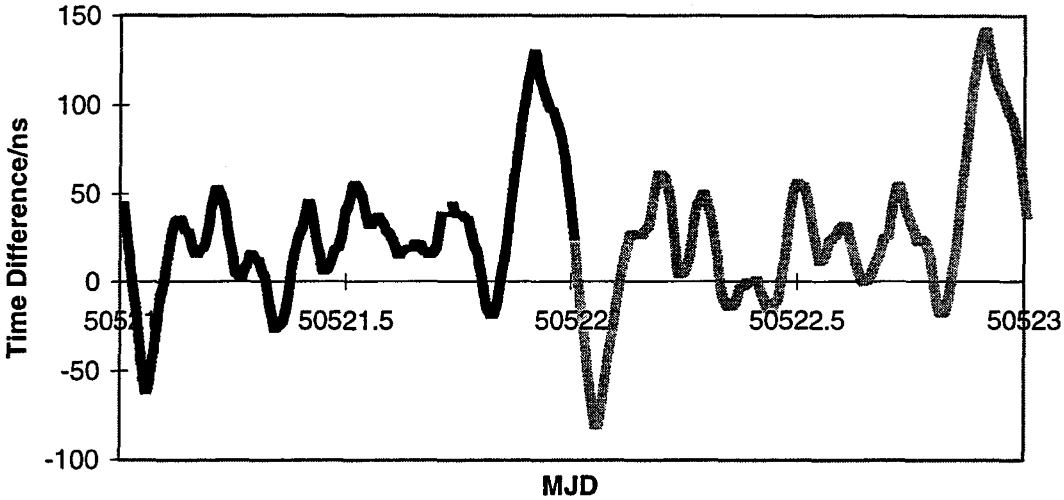

Figure 11: Phase output from a quartz GPSDO examined during the NPL study, after erroneous altitude coordinates have been entered into the unit. Note the repeating diurnal structure in the data.